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Land-Use Change Analysis Using Sequential Aerial Photography and Computer Techniques

The combination of remote sensing and computer techniques was employed to acquire basic land-use data for monitoring urban growth in Lagos, Nigeria.

ABSTRACT: *Research reports from North America and Europe have stressed the utility of remote sensing for the acquisition of basic urban land-use data. This new technology has not been so used in Nigeria.*

In order to acquire basic urban land-use change data for Lagos, Nigeria, sequential black-and-white aerial photographs for 1962 (1:40,000) and for 1974 (1:20,000) were employed. Land-use types were interpreted into acetate overlays, transferred to base maps, and the resulting land-use maps field checked. The land-use data were then input directly into the computer by encoding the dominant land use for each 100 m² grid cell. A 'Land Use Change Detection and Analysis Program' (LUCDAP) developed by the author was employed to provide automatically the area of land occupied by each land-use type during each time period, the magnitude and type of change, and the location (X and Y coordinates) of where changes have occurred. A computer mapping program (MAPIT) was employed to illustrate the spatial pattern and relationships of land-use types and land-use changes.

The land-use statistics generated and the maps produced provide essential guidelines for further indepth analysis and they constitute a data bank which has relevance to many urban studies and planning. The method employed and the result obtained strongly suggest that a combined utilization of remote sensing, especially sequential aerial photographs, and computer techniques offer the most promising opportunity, at this time, for the acquisition of basic urban land-use data so necessary for the study, planning, and management of urban areas in Nigeria as well as in many developing countries.

INTRODUCTION

LAND-USE INFORMATION is one of the essential tools for nearly all urban development efforts. Changes in the use of land are, to a large extent, a reflection of how society responds to socio-economic, institutional, and management practices and, thus, they provide essential input for an objective evaluation of such practices. Yet, research reports relating to urban areas in developing countries, and especially Nigeria, are replete with comments concerning the inadequacy of relevant land-use information. Consequently, effective planning is rendered more difficult. The situation is compounded, and partly caused, by lack of appropriate methodology to acquire background information to aid the decision makers as well as the urban planners.

Fortunately, a number of studies, especially in North America and Europe, have, within the last three decades, demonstrated that remote sensing

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 46, No. 11, November 1980, pp. 1447-1464.

has great potential to provide a cost-effective, timely, and efficient information on land-use changes (Wagner, 1963; Avery, 1965; Falkner, 1968; Richter, 1969; Dueker and Horton, 1971; Milazzo and Lins, 1972; Wray, 1972; Wray, 1973; Simpson *et al*, 1974; de Bruijn *et al*, 1976; Shaklee, 1976; Brothers and Fish, 1978). In contrast, the application of remote sensing in Nigeria is limited. In a forward to the NAS report on the remote sensing projects for developing countries, Cleveland (1977) also noted that "the experience with the use of remote sensing as an aid in resource management in developing countries is still scant that most of their judgements have had to be based on evidence from practical applications in the United States."

In the light of this observation and the urgent need for land-use information, the major objective of this paper is to examine the combined utility of remote sensing, especially sequential aerial photography, and computer techniques for the acquisition of basic urban land-use change information for Lagos, Nigeria. The intent is to describe and explain how sequential aerial photographs and computer techniques have been used to acquire basic land-use change information which can provide answers to some essential questions, in terms of planning requirements, prior to decision making. Planning questions which typically arise concern types of land use that are present, areal extent of each land use, types and location of land-use changes occurring, the magnitude and rate of such changes, and the types of land that are available for development.

The Study Area

Lagos, the Federal capital of Nigeria, was selected for this study for the following reasons: (1) availability of sequential, black-and-white aerial photographic coverage for 1962 (1:40,000) and 1974 (1:20,000); (2) Lagos is the fastest growing urban centre, not only in Nigeria but also in Africa (Adegbola, 1975)—it is the dominant center for the organization of the nation's economy—production, distribution, finances, and business services; (3) great concern has been expressed by the government as well as urban geographers and planners regarding the deplorable situation arising from the unplanned growth of Lagos and lack of adequate background information to aid its development; and (4) the familiarity of the author with Lagos.

Lagos is characterized by depositional landform features with many intricate networks of lagoons and creeks which have created many islands. The terrain is relatively flat (Figure 1).

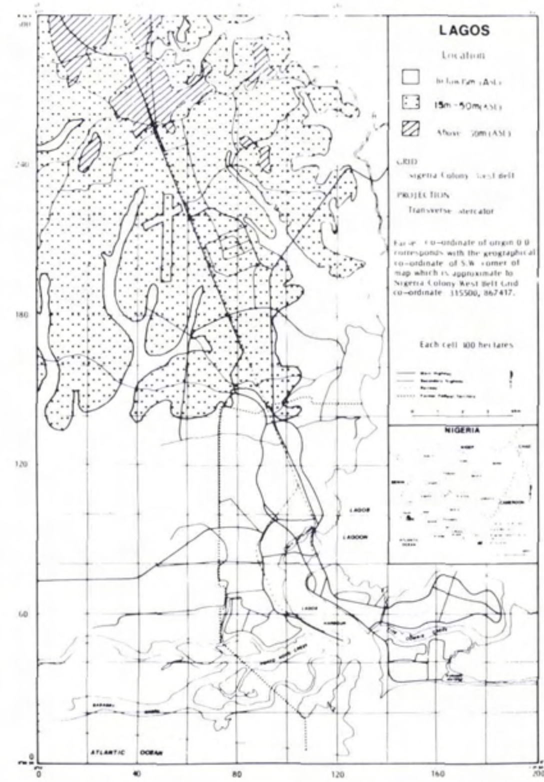

FIG. 1. Map of the Lagos area.

Methodology

The methodology adopted involves two major interdependent components—data acquisition and data handling. The data acquisition component deals with data source, development of land-use classification, data interpretation, mapping unit, creation of data base, transfer of data to the base, and field checking. Data handling, on the other hand, involves the conversion of the data into computer acceptable form, and the development of appropriate computer programs for data manipulation.

DATA SOURCE

The primary data source for this study is comprised of two sets of sequential aerial photographs of Lagos for 1962 (1:40,000) and 1974 (1:20,000). While the flight azimuth for the 1962 aerial photography is East-West, that for 1974 is North-South. Two major constraints imposed by the characteristics of the photographs are (1) the differences in scale precluded a direct comparison of the sequential photographs. This constraint was exacerbated by the difference in flight line azimuth and by the seasonal variation in the time of photography. (2) the minimum mapping unit as well as the level of detail was influenced by the differences in scale. Even though greater detail could be interpreted from the 1974 photographs, the level of object mapability had to be synchronized with that available on the 1962 photographs.

LAND-USE CLASSIFICATION SCHEME

In Nigeria, there is a general lack of pertinent land-use classification schemes. This situation reflects the lack of land-use maps for the urban areas in Nigeria. In developing the land-use classification scheme for this study, the particular characteristics of the study area in relation to source material as well as the objective of the study were taken into consideration.

The multiplicity and complexity of urban land-use patterns, particularly in areas like Nigeria where cities lack proper spatial planning, often produces a large number of use categories which cannot be accurately and spatially mapped at a reasonable, cost-effective scale. For change detection purposes, and to meet the immediate needs, particularly at a metropolitan level, collection of data that can be updated is considered to be of practical significance. Changes in urban land (apart from intra-urban land-use changes) usually involve the conversion of other lands into urban use. In order to provide a basis for a proper assessment and understanding of land-use changes, the classification scheme employed was organized to encompass (1) urban built-up areas, (2) urban vacant land, and (3) non-urban land.

Urban built-up areas encompass land that is used for housing, commerce, industry, institutions, recreational facilities and open spaces, transportation facilities, and utilities. The built-up areas were classified purely on the basis of use which can be essentially and directly observed on aerial photographs. Complications often arise when the idea of ownership is partially introduced or when a parcel of land that is only designated for an urban use is classified as 'used' when it has not actually been put into that use. Such considerations make the assessment of changes difficult.

Urban vacant lands are parcels of land within the urban built-up areas which are not used for any of the activities mentioned above. For instance, a marshland, which is totally engulfed by urban development, is regarded as vacant land within the urban area. Of course, some small pockets of such vacant parcels are, in the case of Nigerian cities, and Lagos in particular, used indiscriminately for 'temporary' activities such as erection of kiosks for petty trading or different forms of workshops. Such uses, even though they add a unique dimension to the physical structure of the urban area of Lagos, were not considered in this study. However, the term 'vacant' is only employed here to emphasize that such parcels are not strictly used for the designated 'urban' purposes. The classification of such parcels was made to reflect their physical potential for urban use.

Non-urban land includes all other land outside the urban built-up areas and vacant land as defined above. The classification scheme adopted is shown in Table 1.

DATA INTERPRETATION

During the process of establishing the land-use classes, a reconnaissance survey of the area was conducted. Although certain characteristics of the images and the objects, such as scale, resolution, tone, texture, pattern, size, shape, and shadow, were used as identification parameters, the pre-survey provided essential interpretation clues. On each stereomodel, the built-up areas were first identified and delineated, followed by vacant and non-urban land uses in that order. At the outset, a minimum mapping unit of one hectare (100 m by 100 m) was decided upon. One hectare on the 1962 and 1974 photographs is represented by squares, approximately 2.5 mm and 5.0 mm respectively. Any land use which covers an area smaller than one hectare was classified with the adjacent use in the most logical manner possible. With many irregularly shaped land-use parcels, variations in the application of the minimum mapping unit was, however, unavoidable.

The interpretation was carried out with the aid of a mirror stereoscope (Wild ST 4 with 3× magnification). Each stereomodel was interpreted onto an acetate overlay. There were 15 stereomodels for 1962 and 37 stereomodels for 1974. On the average each stereomodel took about 2.5 hours, excluding the period for preparation and testing. Some models took over five hours, especially at the initial stage.

The interpretation was essentially restricted to the central portion of each photograph (approximately 6 cm from the principal point). Throughout the interpretation, existing uses, as identifiable on the photographs, were delineated.

Generally, identification of residential *patterns* was relatively easy. However, the classification of residential areas into similar groups was difficult. The degree of difficulty of delineation increases as one moves from the 'planned' residential areas to the 'unplanned' areas. Delineation of industrial and institutional land uses, especially along the fringe areas, presented some difficulties. In some cases, the structures occupy a relatively small portion of the cleared land. In the absence of a visible property line, the delineation of boundary lines became a problem.

It was difficult to separate public buildings from commercial buildings on the one hand, and public buildings from some military premises on the other hand. The structures used for these activities are, in most cases, similar. Many of these areas were marked on the preliminary land-use maps for special field-checking.

Some land-use classes such as hospitals, public buildings, and police premises do not have consistent 'site' or 'cover type' attributes on aerial photographs, to aid in their identification. Those which could not be absolutely assigned to a particular class of use were left for field verification.

TABLE 1. THE LAND-USE CLASSIFICATION SCHEME*

1. RESIDENTIAL**	10. Large plot, 1-2 story, (Flat) buildings with vegetated open spaces.
	11. Medium plot, mostly two story, (flat) buildings, without vegetated open spaces.
	12. Medium plot, mixed, 1-2 story (flat) buildings with small individual open spaces.
	13. Single story row houses with moderate common open spaces.
	14. Mixed traditional and modern 1-3 story buildings.
	15. Old traditional 'court-type' rooming buildings.
	16. Traditional single story rooming buildings interspersed with 2-3 story buildings.
	17. Apartment buildings (four story and above).
	18. New developing residential areas (completed and uncompleted residential structures in close juxtaposition).
2. COMMERCIAL	20. Main commercial center
	21. Scattered, and road side development
	22. Shopping center
	23. Traditional market
3. INDUSTRIAL	30. Industrial complex areas.
4. INSTITUTIONAL	40. Educational (schools and colleges)
	41. Hospital
	42. Public and correctional establishments
	43. Police establishment.
	44. Military establishment.
	45. Other institutional premises.
5. TRANSPORTATIONAL AND UTILITIES	50. Airport premises
	51. Railway stations and terminals
	52. Marine terminals (wharf areas)
	53. Highway rights of way
	54. Automobile parking areas
	55. Utilities
6. RECREATIONAL AND OPEN SPACES	60. Indoor recreation areas
	61. Sport grounds
	62. Parks
	63. Cemetery
	64. Beach
7. VACANT LAND	70. Site under construction
	71. Undeveloped (dry) vacant land (usually cleared)
	72. Undeveloped (dry) vegetated land
	73. Undeveloped (wet) non-forested land
	74. Undeveloped (wet) forested land
8. NON-URBAN LAND	80. Undifferentiated rural villages
	81. Agricultural plantations
	82. Farmland
	83. Forested wetland
	84. Non-forested spottily vegetated wetland
	85. Shrub and secondary forest areas
	86. Sandy areas other than beach
	87. Sand and gravel pits
9. WATER	90. Open water body

* See Adeniyi (1978) for full explanation of the land-use categories.

** A brief note on some essential characteristics of the residential category.

(1) A 'flat' residential building refers to a building that is partitioned into separate dwelling units, each unit being self-contained. That is, each unit has its own kitchen, toilets and bathrooms, and, in some cases, separate outlet. Ideally, a 'flat' dwelling unit contains a single family.

(2) A 'rooming' residential building refers to a building which is shared, by separate families, room by room. In such buildings a room (or a set of n rooms) constitute a separate dwelling unit, while kitchen, toilet, bathroom (where available within the building), and outlet are common facilities. Essentially, all the traditional residential buildings are in this form. The traditional 'court-type' residential buildings are also in this form. The difference is that all the families of the traditional chiefs who first settled in Lagos had their houses built to form a rectangular-like pattern with a moderate (common) open space at the center for meetings and general recreational activities. With higher education, higher standard of living, and the consequent need for privacy by the educated elites, some of the compounds have been replaced by a set of separate, one, two, or three story residential buildings. In some cases, the basic rooming structure is still maintained.

(3) A large plot residential building usually occupies an average area of 2000 m^2 (e.g., residential class 10). A Medium plot residential building usually occupies an average area of 500 m^2 to 1000 m^2 (e.g., residential classes 11, 12, and 13).
Most of the plots in the 'unplanned' residential classes 14, 15, and 16 occupy areas less than 500 m^2.

In the fringe areas, it was not easy to separate farm land from vegetated vacant land.

TRANSFERRING DATA TO THE BASE MAP

A 1:20,000 base map was selected. At this scale, it was easy to encode data on the basis of 100 m by 100 m grid cells. The base map was made by enlarging, photographically, the available (1964) 1:50,000 topographical map of Lagos.

The transfer of land use data from the interpreted overlays to the base map was accomplished by using a Bausch and Lomb Zoom Transfer Scope (ZTS). The transfer of the 1962 land-use data to the base map was relatively easy because the base map was originally made from the 1962 photographs. However, each model had to be shifted several times because of the relatively small field-of-view of the ZTS.

The transfer of the 1974 land-use data to the base map presented some difficulties. Changes along the coast, and changes in the alignment of some roads, made the transfer difficult. Two approaches were adopted to aid the transfer. First, some points, especially road junctions, were marked on the stereomodels and were visually located on the base map. These points were later used as control points. Second, the already completed 1962 preliminary land-use map was placed below the base map for 1974 so that land-use boundaries (where changes had not occurred) could be drawn. Each of the steps unavoidably introduced some errors such as incomplete land-use polygons, omission of land-use codes, and omission of small land-use polygons. To reduce such errors to a minimum, each interpreted stereomodel was compared with the 'preliminary' land-use maps.

FIELD CHECKING AND COMPLETION

Notwithstanding the constraints imposed by the gap of 15 years and 3 years between the field work period (June-July 1977) and the dates of photography (1962 and 1974), the lack of other sources of compatible information, and the rapid land-use changes occurring in Lagos, certain approaches made the verification of the accuracy of the air photo interpretation possible.

On the preliminary land-use maps, some areas where doubts existed as to their correct identification were marked with an '×'. The checking of these areas did not present any problem in the field.

In order to ensure a fair coverage of the study area, some land-use classes which are located in many parts of the city were selected for checking. Included in the list are schools, hospitals, markets, police station and barracks, and public buildings. The structures containing those activities are more stable and could therefore be used as indicators of API accuracy. Out of 78 schools pre-selected on the 1974 land-use map for checking, 77 were correctly interpreted. Also, all the pre-selected markets, police barracks, and hospitals were correctly interpreted. Indeed, there are more of these establishments which did not meet the minimum mapping unit and which have been classified with other uses.

Another approach employed was related to boundary checking. Boundaries between such land-use classes as residential and central commercial area, residential and road side development, central commercial area and the institutional land use, and boundaries separating one residential class from the other were field checked. The increasing intensification of residential areas by uncontrolled subdivision, and the infilling of open spaces within buildings by other structures, made boundary checking difficult. By this process, some residential areas had changed (between 1974 and 1977) to the extent that they had graduated to a higher density class (for example, residential class 18 in 1974 becoming residential class 16 or 14 in 1977). Similarly, a high degree of commercialization of the residential areas surrounding the main commercial center was noticed in the field; hence, the boundaries of these land uses as delineated on the map were retained.

Finally, all the errors found in the field were corrected on the preliminary land-use maps. During the process of correction, the photographs had to be re-interpreted (where found necessary) to ensure that the situations represented on the final maps were those of 1962 and 1974 and *not* that of 1977.

DATA HANDLING FOR CHANGE DETECTION

The line maps produced from the preceding steps represent the inventory of the land-use patterns for the two periods. Visual comparison of these maps, either by side-by-side or by overlay method, is considered to be time consuming. In order to derive optimum benefit from the information contained on the maps, a computer assisted technique, based on a grid referencing system, was adopted. The logic of using the analytical technique and the computer program is discussed in the following paragraphs.

Let us assume that there are n land-use categories at each time period. The intent is to compare each land-use category with all the others. For each land-use category, there will be $(n - 1)$ possible changes. For n land-use categories, the number of possible changes becomes $n(n - 1)$.

Let us further assume that the land-use information is aggregated into cells and that each land-use map for each time period contains k cells. In order to obtain change information, all cells on the map at time period t_1 must be compared with their corresponding cells at time period t_2. That is, there are k operational steps. Detection of possible changes, therefore, involves $kn\ (n - 1)$ operational steps. Given a map with 100 cells at each time period and 20 land-use categories, the number of operational steps is $100 \cdot 20(20 - 1) = 38{,}000$.

A manual operation of these steps has meant a reduction in the number of categories to a few major ones and the use of larger cell size (that is, fewer number of cells). For monitoring purposes, a faster method which is not only more economical but also less prone to error and which can handle a large volume of spatial data seems to be of practical significance.

Given the large number of operational steps required to obtain change information, and the need for rapid assessment of urban land-use changes, LUCDAP was developed. LUCDAP is a simple Fortran program written by the author to handle a large volume of data spatially aggregated into grid cells. Each grid cell has an x,y coordinate and a data value. The program accepts numerically coded data values. It was written to accept up to 90 land-use categories with an option to combine them into 9 major categories.

LUCDAP has one main program and three subroutines. The main program reads and prints (if desired) the data for the two time periods and counts and classifies the land-use data for each time period into major categories. It provides the area of land occupied by each land use at each time period (see Tables 2 & 3A). The first subroutine compares corresponding cells in both periods in order to detect what types of changes are occurring. The subroutine is called COMPER for comparison of periods.

COMPER compares each major land-use category and class by stating COMPER (1,2) and prints out the changes as illustrated in Table 3B (1 and 2 refer to periods t_1 and t_2). By inspecting the output of COMPER, certain changes might be noted which are of particular interest to the researcher. The researcher may then want further information about the location of the desired changes.

The second subroutine, called COMCAT, compares land-use categories of interest and provides information about the locations of changes. It does so by simply stating the categories desired; thus COMCAT (1,4) means land use coded as 1 is to be compared with land use coded as 4 for change detection and for locational specification of where changes have occurred. COMCAT output is illustrated in Table 3C.

Since the major categories may contain many classes, a particular class of use may be of interest. Thus, the third subroutine, called COMCLS, compares land-use classes of interest and indicates the location of the changes. An instruction like COMCLS (11,41) means that land-use class 11 is to be compared with land-use class 41 and the locations of change specified. An example of the COMCLS output is illustrated in Table 3D. If desired, change files can be created by punching the outputs for subroutines COMCAT and COMCLS.

The program provides the basic quantitative information about land-use inventory, type of change, amount of change, and the location of where changes have occurred. It is particularly suitable for areas lacking computer plotting facilities. If the original data base is transferred onto a stable gridded Mylar, location of changes can be performed rapidly, economically, and more accurately by employing the program. Since the location of change detected by the program is specified by the x and y coordinate, such a location can then be manually plotted or identified by simply following the x and y direction.

It is often desirable to portray land-use data on maps for effective visual interpretation. However, it is difficult cartographically to portray many land-use categories on a map without jeopardising the intelligible interpretation of the information contained on such a map. Every manual redrawing of selected information from such a map is likely to compound errors. In order to illustrate effectively the spatial patterns of different land uses as well as the distributional patterns of land-use changes, computer mapping was made a complementary component of the land use change detection.

The mapping program used is called MAPIT*. It is a Fortran program designed to draw a shaded (choropleth) map on an x,y drum plotter. The program accepts gridded spatial data. Like the Land-Use Change Detection Program, each grid cell has an x and y coordinate and an associated data value. The program can produce a maximum of 11 different patterns (representing 11 different land-use classes). With minor adjustments in the program, many land-use classes can be combined for mapping. The relative proportion of each land-use class in terms of percentages is provided by the program. It accepts a maximum of 300^2 cells.

Before the programs (LUCDAP and MAPIT) could be used, the mapped data had to be converted to machine readable format. In this study, a manual grid encoding technique was used. The 100 m by 100 m grids were carefully drawn onto a clear and stable Mylar. Each map was encoded twice (for checking purposes). The dominant land use within each cell was recorded.

Four assistants were employed for the coding. Each map was first coded by a team of two assistants (one reads, the other records). After the completion of the first coding, the maps were interchanged for the second coding. The recorder only noted the location of the cells where differences in

* MAPIT was written by Dr. Ross Newkirk of the School of Urban and Regional Planning, University of Waterloo, Waterloo, Ontario, Canada.

TABLE 2. AN ILLUSTRATION OF A GRIDDED DATA BASE FOR PERIODS T_1 AND T_2*

T1

11	11	11	30	11
11	11	40	40	10
41	41	41	41	10
11	11	11	11	10
41	10	10	20	20

T2

11	11	30	30	11
41	11	40	40	40
41	41	41	41	10
11	10	41	41	10
41	41	10	20	20

(Axes in both grids: y from 0 to 5, x from 0 to 5.)

* Each cell is one hectare (100 by 100 metres). The code in each cell represents a particular land-use class as interpreted from aerial photographs of each time period. The land-use information is converted to computer acceptable form.

TABLE 3. EXAMPLES OF THE 'LUCDAP' OUTPUTS

A. *SUMMARY OF LAND USE* (in ha)

Time Period t_1		Time Period t_2	
Land-Use Class	Area (ha)	Land-Use Class	Area (ha)
10	5	10	4
11	9	11	4
20	2	20	2
30	2	30	3
40	2	40	3
41	5	41	9

This output is from the main programme. It is related to the information on the gridded data base shown in Table 2.

B. *EXAMPLE OF 'COMPER' SUBROUTINE OUTPUT*

Comparison of Periods $t_1 : t_2$

Change from category	1 to 3 is 1 ha
Change from category	1 to 4 is 5 ha
Change from class	10 to 40 is 1 ha
Change from Class	11 to 10 is 1 ha
Change from class	11 to 30 is 1 ha
Change from class	11 to 41 is 4 ha
6 Category Changes in All	
7 Class Changes in All	

C. *EXAMPLE OF 'COMCAT' SUBROUTINE OUTPUT*

Compare Categories 1:4

5 Hectares of Changes from 1:4
Change from 1 to 4 in location (1,2)
Change from 1 to 4 in location (2,3)
Change from 1 to 4 in location (2,4)
Change from 1 to 4 in location (4,1)
Change from 1 to 4 in location (4,5)

NOTE: The first number of the location refers to the rows and therefore to the y-axis and the second number to the columns, that is the x-axis. If there is no change between categories 1 and 4, the program will simply say there is no change.

D. *EXAMPLE OF 'COMCLS' SUBROUTINE OUTPUT*

Compare Classes 11:41

4 Hectares of Change from 11 to 41
Change from class 11 to 41 in location (1,2)
Change from class 11 to 41 in location (2,3)
Change from class 11 to 41 in location (2,4)
Change from class 11 to 41 in location (4,1)

data value between the first and the second reader occurred. In the 1962 Land-Use map, 56 differences were discovered against 98 for 1974. The differences were traced to the factors shown in Table 4.

The most common and most important error is due to judgement factor—the decision about what to record for a cell where three or more land-use polygons intersect. Most of these errors occurred in the built-up areas.

Incorrect land-use codes and incomplete land-use polygons are not unusual problems. If the area of land use were to be calculated manually, such errors could have been ascertained. With 60,000 data points for each time period, the above errors could be regarded as negligible. However, the figures are only indicative of the usefulness of the double encoding system employed. Certainly, minor judgemental errors would still exist.

After all the errors had been corrected, the data were key-punched onto a disk through the University of Waterloo IBM (VM)/370 and were later transferred onto a computer tape. Because of the volume of the data, a special interactive program called DATAIN was written to help generate a data file containing the x,y grid coordinates and a data value for an area described by

$$1 \leq x \leq 200$$
$$1 \leq y \leq 300$$

It facilitates the production of the data file by (1) generating the x,y grid coordinates, (2) reading data values entered by the operator for the points, and (3) checking the validity of the data values entered. The program is re-entrant. The operator can halt the program at any x,y grid coordinates and resume execution when convenient.

For example, if the points (1,1), (2,1), (3,1), (4,1), and (5,1) all had a data value 30, the program needs only the starting point, the data value, and the last x-coordinate, that is,

1, 1, 30, 5

This information would result in the program writing the following records to the data file:

TABLE 4. LAND USE CODING ERROR

Factors	No. of Cells in 1962 Land Use Map	No. of Cells in 1974 Land Use Map
Judgement	32	59
Incorrect land-use code	9	21
Incomplete land-use polygon	11	18
Others (misreading or incorrect recording)	4	—
TOTAL	56	98

1	1	30
2	1	30
3	1	30
4	1	30
5	1	30

The operator is expected to continue entering data in this manner until the value entered for x is 200.

In order to edit the data file generated by DATAIN, another short program called CHECK was written. CHECK reads the data file generated by the program DATAIN and produces a listing of these data which is suitable for manual checking. The program also checks the order of the x,y coordinates in the data file for sequence errors and for missing data.

The listing generated by CHECK contains the minimum amount of information required to verify that the data on the file generated by the DATAIN are accurate. Only the x,y coordinates and data value of the first point at which the data value changes is listed. For example, if the data file contains the following records:

x	y	*Data*
1	1	30
2	1	30
3	1	30
4	1	30
5	1	40

the listing would contain simply

1	1	30
5	1	40

This compact method of listing the data in the data file provides the researcher with fewer numbers to compare. Only the points at which the data change need be considered.

APPLICATION OF THE LAND-USE CHANGE DETECTION AND ANALYSIS PROGRAM (LUCDAP)

After these data had been thoroughly checked for punching errors, they were organized into six separate files, each containing 10,000 data points.

As a further check on punching errors, coding errors, and land-use boundary correspondence between the two periods, the Land Use Change Detection and Analysis Program was run. The program, through the subroutine COMPER, was instructed to compare all the corresponding cells using mainly the major land-use categories. Each separate data file was submitted to LUCDAP. By carefully examining the land-use change statistics produced by LUCDAP, some unexpected changes were observed. Such changes included a change from water to transportational land use; from residential land use to institutional land use; from residential land use to vacant land; from commercial land use to transportational land use. Two hundred and two such changes were noted. The LUCDAP was again initiated (through its subroutine

COMCAT) to print out the coordinates of the cells where those changes have occurred. The coordinates were then used to locate the area on the maps. Only 81 were found to be 'true' errors. Out of these, 29 were punching errors and 52 were due to variations in land-use boundaries between the two periods. This was expected because of the difficulty encountered during the initial transfer of data to the base map. The photographs were again used to correct the errors. The corrected data files were again submitted to the Land Use Change Detection and Analysis Program for the production of land-use and land-use change statistics.

All the maps, with the exception of the change map, make use of the original data. A new data file was created for the change map. The change statistics from LUCDAP revealed that the major changes in Lagos were from Vacant and Non-Urban to Urban Land. Consequently, a change data file that could be used directly with MAPIT was created through a program called CHANGE.

The Fortran program CHANGE reads the 1962 and the 1974 data files and generates a new data file for the major land-use changes. The program examines each data point for both years and, if any of the desired changes have occurred, the x and y coordinates of the points are written to the new data file followed by a new code. For instance, if there is a change from land use category 7 to land use category 1 at point i,j, the new change record will contain i,j: 71 where 71 becomes the new land-use code (samples of the type of map generated are shown in Figures 2, 3, and 4).

MAGNITUDE AND RATE OF CHANGE

Table 5 shows the area of land under each major land-use category for 1962 and 1974, respectively, as well as the magnitude and rate of change between the two periods. While urban land experienced an increase of 5184 hectares between 1962 and 1974, vacant land increased by 1181 hectares and non-urban land experienced a decrease of 6354 hectares. Figure 5 illustrates the relative situations for both time periods.

With respect to the major urban land uses, residential land experienced the largest increase, 3341 hectares, representing 64.4 percent of the total land converted to urban use, with an average annual constant growth rate of 7 per cent. Institutional and industrial land uses increased by nearly the same amount of land but, while the average annual growth rate of the former was 7.5 percent,

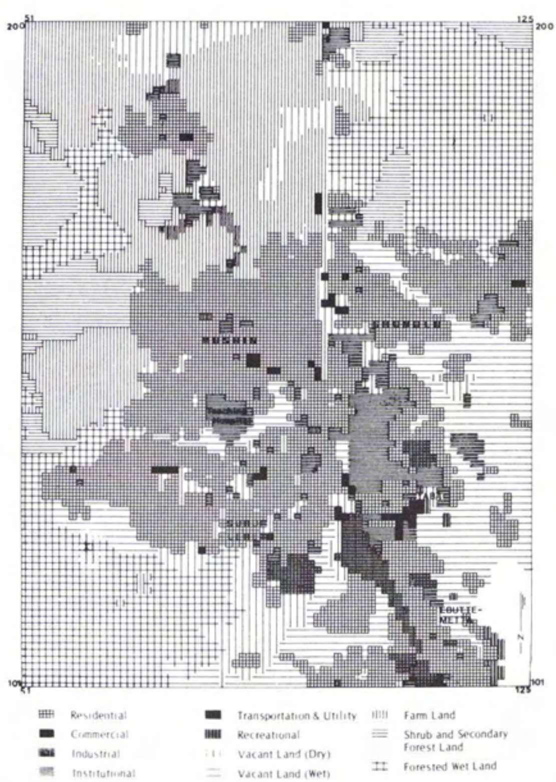

FIG. 2. A sample of the computer land-use map of part of the Lagos mainland, 1962.

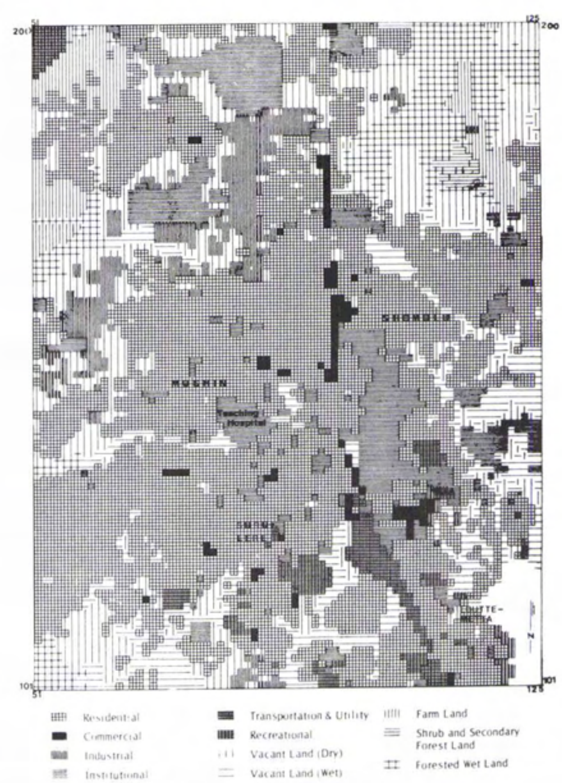

FIG. 3. A sample of the computer land-use map of part of the Lagos mainland, 1974.

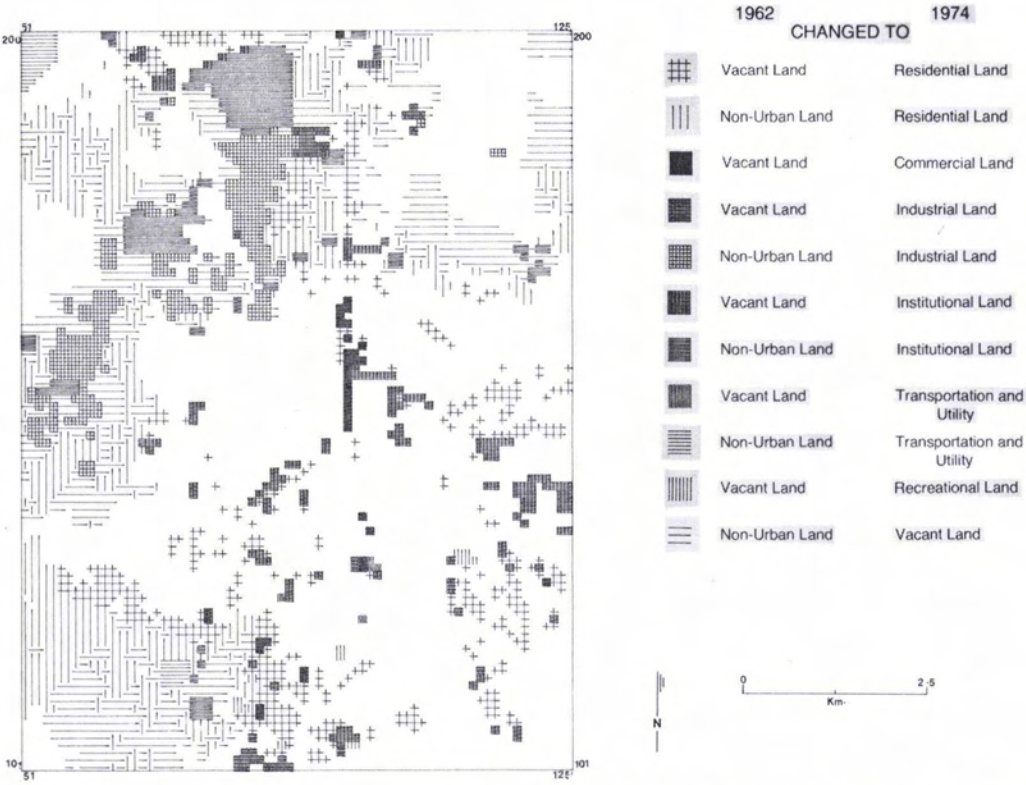

FIG. 4. A sample of the computer generated land-use change map of part of mainland Lagos, 1962-1974.

that of the latter was 13.3 percent. Commercial land increased at an average annual growth rate of 5.2 percent with over 62 percent of the increase coming from scattered and road side development. Transportation and utility experienced a total increase of 227 hectares, which amounted to an average annual growth rate of 5.2 percent. Recreational and open spaces only had 0.5 percent average annual growth rate (see Figure 6).

TYPES OF CHANGES

Although the magnitude and rate of change provide an overview of the growth process, it is the type of change which provides an important input for the evaluation of the process. Table 6 shows the major inter-categorical land-use change types in a matrix form.

An examination of Table 6 shows a clear evidence of the conversion of vacant land and non-urban to urban land with a few intra-urban land-use changes. Out of 8844 hectares of converted land, vacant land and non-urban land accounted for 23.5 and 73 percent, respectively. This shows a strong lateral expansion of the urban area of Lagos. Besides residential land, industrial and institutional land accounted for 8 and 8.5 percent of the total converted land, respectively.

Another significant result revealed in Table 6 is the considerable amount of non-urban land converted to vacant land (3220 ha). The dynamics of land-use change is shown in Figure 7. In this figure, A represents the urban land in 1962, $B_1 + B_2$ represents vacant land in 1962, and $C_1 + C_2 + C_3$ represents non-urban land in 1962. By 1974, the proportion of vacant land represented by B_2 had been converted to urban land. Similarly, the portion of non-urban land represented by C_3 had been converted to urban land, while C_2 was converted to vacant land. Thus, the urban land in 1974 was represented by $A + B_2 + C_3$, vacant land by $B_1 + C_2$, and non-urban land by C_1.

Notwithstanding the invaluable information contained in the major land-use change matrix, further information about the nature of changes within each land use category is often more important. Because of the significant conversion of vacant and non-urban land to urban use, Tables 7 and 8 show, as an illustration, how different vacant types and non-urban land have changed to different residential land-use classes.

Table 7 shows that 64.3 percent of the 1171 hectares of vacant land converted to residential land is dry land. While over 75 percent of the dry vacant land is converted to "planned" residential

TABLE 5. LAND USE AND LAND-USE CHANGE IN LAGOS 1962–1974*

Land Use Categories	1962 Area (in Ha) A	1974 Area (in Ha) B	Change (in Ha) (B − A)	Change % $100\frac{(B-A)}{A}$
Residential	4001	7342	3341	83.5
Commercial	191	310	119	62.3
Industrial	446	1155	709	159.0
Institutional	836	1589	753	90.0
Transportational & Utilities	447	674	227	50.8
Recreational & Open Spaces	492	527	35	7.1
SUB-TOTAL URBAN	6413	11597	5184	80.8
Primary (dry) Vacant Land (70, 71, & 72)**	2157	3873	1716	79.5
Marginal (wet) Vacant Land (73 & 74)**	3052	2517	−535	−17.5
SUB-TOTAL VACANT	5209	6390	1181	22.7
Farm Land & Associated Villages (80, 81, & 82)**	5622	6278	856	11.7
Shrub & Secondary Forest Land (85)**	8000	4887	−3113	−38.9
Wet Land & Other Non-Urban Land (83, 84, 86, & 87)**	13486	9589	−3897	−28.9
SUB-TOTAL NON-URBAN (EXCLUDING WATER)	27108	20734	−0394	−23.4
WATER	8070	8059	−11	−0.1
TOTAL STUDY AREA	46800	46800	—	—

* Based on computer output of gridded land use data.
** Codes for land use classes.

classes, over 87 percent of the wet vacant land is converted to high density, "unplanned" residential classes. The modern, medium size plot, two story flat buildings, and the traditional single story rooming buildings each received over a quarter of the converted vacant land.

Table 8 shows the types of changes from non-urban land to residential classes. The table shows that (1) eighty-six hectares of 'agro' villages have become part of urban residential land; (2) one quarter of the 2255 hectares of non-urban land converted to residential land came from farm land, 35.3 percent from non-forested wet land, and 28 percent from shrubs and secondary forest land; and (3) over 85 percent of the 2255 hectares of non-urban land converted to residential land went to high density, "unplanned" residential areas. Nearly half of the converted non-urban land went to the traditional, single story rooming buildings (for further details, see Adeniyi 1978).

In short, some of the major findings resulting from this approach as it relates to land-use changes in Lagos are as follows: (1) Urban land use of Lagos for both 1962 and 1974 was dominated by residential land use (over 60 percent); (2) out of 8844 hectares of land converted to other uses, 73 percent came from non-urban land and 23.5 percent from vacant land while over 40 percent of the converted non-urban land came from wetland and 25 percent from farmland; (3) urban land experienced a tremendous lateral growth of 5184 hectares (80.8 percent) representing 58.6 percent of the total hectares of land use changes; (4) residential land accounted for over 60 percent of the total urban land increases; (5) three quarters of residential growth occurred in the high density and

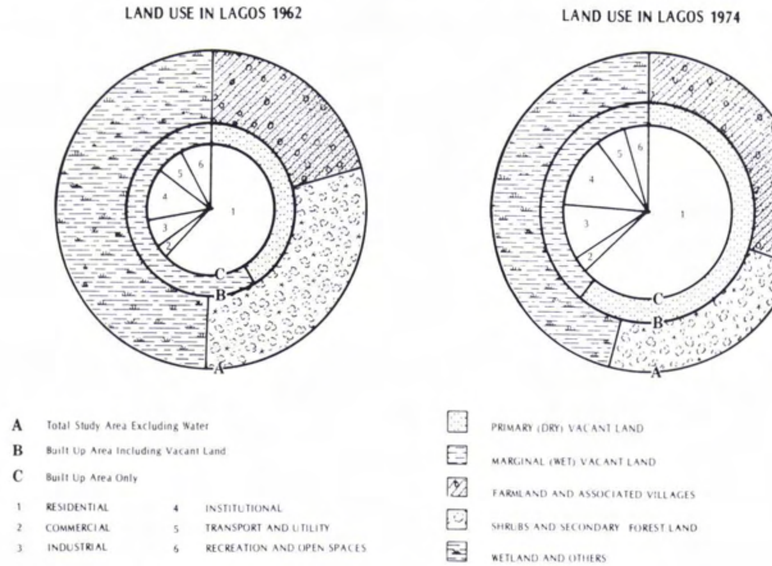

FIG. 5. Relative land use in Lagos in 1962 and 1974.

'unplanned' residential classes; (7) urban land increase was accompanied by an increase in vacant land; (8) the growth of the urban-built up area outside the former Federal territory (FFT) was four times that of the FFT; and (9) over fifty percent of the urban land increase occurred in wetland areas.

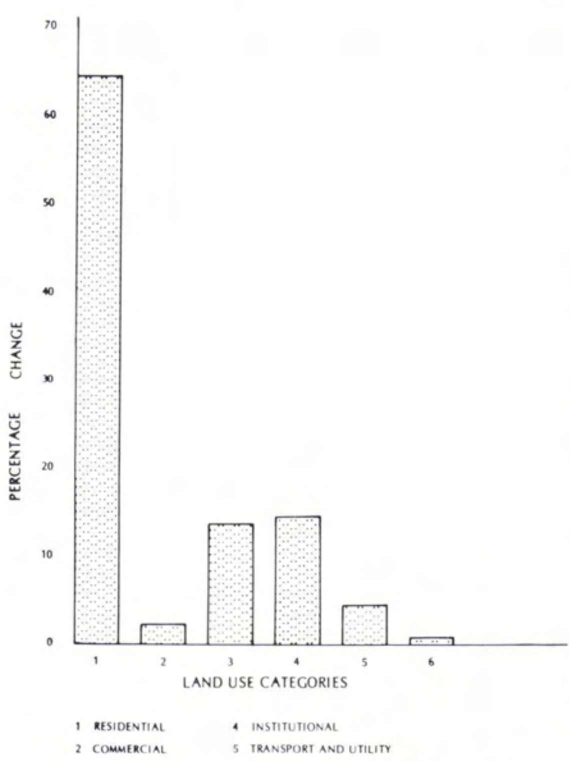

FIG. 6. Distribution of land-use changes in the built up areas of Lagos, 1962-1974.

AN OVERVIEW OF APPROACH

One hectare was selected for the mapping and storage of the data. Although the mapping unit is almost the smallest land-use unit that could be mapped on the 1962 aerial photograph, it was found, on the average, suitable for the purpose of assessing urban land-use changes. Certain important urban land uses which tend to occur in small parcels (e.g., traditional markets, schools, and shopping centers) were mapped. If a larger minimum mapping unit had been used, it would have resulted in an underestimation of such land uses. While the use of one hectare as a mapping unit did not completely remove the occurrence of such error, it reduced its magnitude.

However, one hectare as a mapping unit was found to be more suitable for the "planned" areas of Lagos than for the "unplanned" areas. In the latter areas, the intensity and complexity of land use demands a smaller mapping unit for a large scale study.

The use of one hectare as a data storage unit enhanced an accurate estimation of the amount of land under each use. By applying LUCDAP to the encoded land-use data, the necessary basic statistical and locational information about land use and land-use changes is produced. Six data files were created, each containing 10,000 data records. For each data file, it took the computer an average of 7.42 minutes real time (3.80 minutes computer time) to produce all the required information. For the whole of the study area, 44.51 minutes real time (22.79 minutes computer time) was used. The program provides a quick and detailed assessment

TABLE 6. MAJOR LAND USE CHANGE MATRIX 1962–1974 (in Ha)* CHANGE TO 1974

CHANGE FROM 1962 — Land Use Code	CHANGE TO 1974: 1	2	3	4	5	6	7	8	9	TOTAL (F)	% OF TOTAL CHANGE
1. Residential	0	32	3	21	16	0	15	0	0	87	1.0
2. Commercial	0	0	0	0	3	0	0	0	0	3	0.03
3. Industrial	0	0	0	0	0	0	0	0	3	3	0.03
4. Institutional	2	0	0	0	0	0	0	0	0	2	0.02
5. Transportational	0	0	0	0	0	0	0	0	0	0	0
6. Recreational	0	2	0	11	1	0	0	39	26	79	0.9
7. Vacant Land	1171	67	279	394	58	53	0	48	6	2076	23.5
8. Non-urban land	2255	21	427	329	101	11	3220	0	92	6456	73.0
9. Water	0	0	3	0	48	50	22	15	0	138	1.6
TOTAL (T)	3428	122	712	755	227	114	3257	102	127	8844	
NET CHANGE (T − F)	3341	119	709	753	227	35	1181	6354	−11		
% OF TOTAL CHANGE	38.8	1.4	8.0	8.5	2.6	1.3	36.8	1.2	1.4		
NET GAIN/ LOSS % OF TOTAL CHANGE	37.8	1.3	8.0	8.5	2.6	0.4	13.4	−71.8	−0.1		

* Summarised from LUDCAP output.
F = Decrease in landuse categories due to change.
T = Increase in landuse categories due to change.

of land-use change. It could be adapted for use for other types of data, provided the data are coded numerically into grid cells. The interval of 12 years between the two periods covered by this study (1962-1974) is not suitable for the monitoring of rapidly changing urban centers such as Lagos. A shorter interval of two years would be better for the detection of land-use changes.

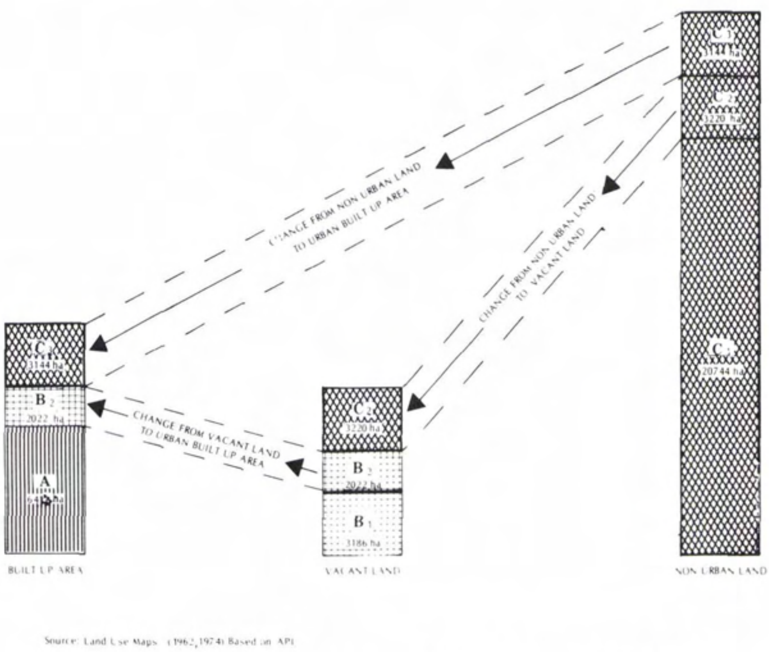

FIG. 7. The dynamics of land-use change in Lagos, 1962-1974.

TABLE 7. CHANGE FROM VACANT LAND TO RESIDENTIAL LAND 1962–1974 (in Ha)*

VACANT LAND 1962 Land Use Code**	RESIDENTIAL LAND 1974										
	10	11	12	13	14	15	16	17	18	TOTAL	% LOSS
71	158	238	46	1	60	6	51	20	5	585	50.0
72	0	3	0	0	20	0	74	0	70	167	14.3
73	14	53	0	4	31	10	98	1	27	238	20.3
74	12	6	0	0	44	0	90	0	29	181	15.4
TOTAL	184	300	46	5	155	16	313	21	131	1171	100
% GAIN	15.7	25.6	3.9	0.4	13.2	1.4	26.7	1.8	11.2	100	

* Based on the output of COMPER.
** See Table 1 for definitions of land-use codes.

The computer mapping employed is meant to highlight and facilitate the illustration of the spatial pattern of any land use or combination of land-use categories. With the computer mapping employed, a particular land-use category could be mapped separately for quick assessment of spatial distribution. An average of 90 minutes is needed to produce an 11-category land-use choropleth map (on the University of Waterloo 30-inch Drum Plotter) for the study area. A shorter time is needed for fewer categories and for larger grid cells. An important point about computer mapping of land use is that, once the data for an area are correctly stored either on cards, on tapes, or on disks, subsequent mapping of all or parts of the area will remain correct. This makes the data more readily accessible and easy to update.

SUMMARY AND CONCLUSION

The combined use of sequential aerial photographs and computer programming and analysis made it possible to generate a large volume of land-use data for Lagos. The fundamental importance of the data generated (which are stored on computer tapes for easy access) is that they provide essential guidelines for further indepth analysis and they constitute a data bank which has relevance to many urban studies and planning such as urban physical planning, modeling and predicting urban growth, planning the use of vacant lands, development of urban fringe areas, zoning regulation, etc. In addition, the data could be used together with additional appropriate information for the estimation of other concerns such as water supply, solid waste disposal, population number and population densities, etc (see Adeniyi, 1978).

In carrying out this study, a lack of standard and mapped statistical units (e.g. mapped administrative boundary, census tracts, enumeration districts, etc.), precluded accurate use of previous research results for Lagos, except in a qualitative sense. To benefit more from modern technological developments and scientific enquiries, research on developing a set of standard and mapped "statistical units," which various investigators could use as bases for data aggregation, data analysis, and storage, is needed. Another important research area is the development of a standard (open-ended) land-use classification scheme which would reflect generally the 'true' situation in urban centers in Nigeria.

Finally, it needs to be re-emphasized that studies relating to land-use structure of cities in

TABLE 8. CHANGE FROM NON-URBAN LAND TO RESIDENTIAL LAND 1962–1974 (in Ha)*

NON-URBAN LAND 1962 Land Use Code**	RESIDENTIAL LAND 1974										
	10	11	12	13	14	15	16	17	18	TOTAL	% LOSS
80	0	0	0	0	1	0	86	0	3	86	3.8
81	0	0	0	0	0	0	0	0	1	1	0.04
82	38	96	0	0	30	0	254	4	158	580	25.7
83	0	1	0	0	16	0	87	1	56	161	7.1
84	0	57	10	0	14	0	363	3	349	796	35.3
85.	4	34	0	0	51	0	250	7	285	631	28
TOTAL	42	188	10	0	112	0	1036	15	852	2255	100
%	1.9	8.3	0.4	0	5.0	0	45.9	0.6	37.9	100	

* Based on the output of COMPER.
** See Table 1 for definition of land-use codes.

developing countries are scarce. In the western world, the spatial structures of cities are generally known. Such knowledge about cities in developing countries is often lacking. Effective planning is frequently rendered difficult owing to a lack of up-to-date information on land use and of the means of acquiring such information. The methods developed in this study, and the results obtained, suggest strongly that the combination of remote sensing techniques, especially interpretation of sequential aerial photography and computer techniques, offer the most promising opportunity, at this time, for the acquisition of basic data which are necessary for the monitoring of urban growth. It is recommended that research programs, similar to the one reported in this paper, be carried out in other urban centers in Nigeria as well as in other developing countries.

ACKNOWLEDGMENT

The author wishes to acknowledge the financial and material support provided by the Universities of Lagos (Nigeria) and Waterloo (Ontario, Canada) for this study. The assistance provided by Professors D. K. Erb, A. Kesik, and R. Newkirk, and Mr. and Mrs. Oliver, all of the University of Waterloo, are gratefully appreciated. Special thanks are due to J. R. Wray of the U.S. Geological Survey on whose advice this paper was written.

APPENDIX

BRIEF EXPLANATION OF LAND-USE CATEGORIES

Residential Land Use. This category includes parcels of land which are primarily developed for dwelling purposes. Nine classes were recognized (Table 1). Essentially, the classification of the residential areas into different residential classes was based on the shape, height (number of floors), density, spatial arrangements of buildings, landscaping, presence of gardens, and street trees. These 'physical spatial variables' depict some cultural and dwelling characteristics, hence the classes were designated to reflect such values as shown in Table 1. Figures A-1 and A-2 illustrate some of the residential classes. While residential classes 10, 11, 12, 13, and 17 represent essentially planned residential classes, other classes (14, 15, and 16) are essentially 'unplanned'.

In this category, access roads, community facilities such as schools, and churches, which occupy areas smaller than the mapping unit (one hectare), are included. Petty trading and craft activities are associated with this category, especially in the privately developed and unplanned residential areas.

Not included in this category are residential zones associated with military, police, schools, and colleges. Also, dwellings within structures which are not *primarily* used for residence are not included (e.g., hotels or dwellings within commercial buildings).

Commercial Land Use. This includes parcels of land developed and used for activities involving purchase and consumption of goods and services. The main commercial center corresponds with the central business district with many business offices, banks, and wholesale and retail shops. (see Figure A-2, code 20). The scattered and road side developments include shops, hotels, gas stations, restaurants, some institutions, and associated open spaces. Usually the structures containing these activities are larger than the surrounding structures. The shopping center is an integrated collection of stores with associated parking and access facilities. The traditional market areas are parcels of land used for daily meeting of people for the purchase and sale of mainly household goods. They are held in tent-like row structures. They appear as parallel regular ridges on the photographs (see Figure A-2, code 23).

Industrial complex areas. These include both heavy and light manufacturing industries. Nearly all the main industrial establishments in Lagos are in estates. Many different industrial activities are mixed together in the estates to the extent that each one could not be consistently identified and delineated on the aerial photographs used and with a minimum mapping unit of one hectare. Some industrial establishments lack clear property boundary.

Institutional. This category includes all activities that are associated primarily with community organization, protection, and general social and cultural welfare. It includes schools and colleges, hospitals, military and police areas, prisons, ministries, and other public establishments. Included in the class 'other institutional premises' are large churches, mosques, mass media, and information centers which meet the minimum mapping unit of one hectare.

Transportation and utilities. This category includes activities involving vehicles in the conveyance of passengers and goods, and the production-distribution of utilities such as water and energy supplies, refuse, and sewage treatment and disposal plants. Included in the utility class are activities involving storage of goods, e.g., buildings for indoor storage such as the public works department stores (P.W.D. Stores) and the open area for storage.

All transportational activities which do not meet the minimum mapping unit are included in other uses.

Recreational and open spaces. These include activities involving indoor assembly for entertainment and outdoor activities for similar purposes. The class 'sport grounds' includes golf courses, stadiums, and tennis courts, but it excludes those in schools, colleges, and military and police areas.

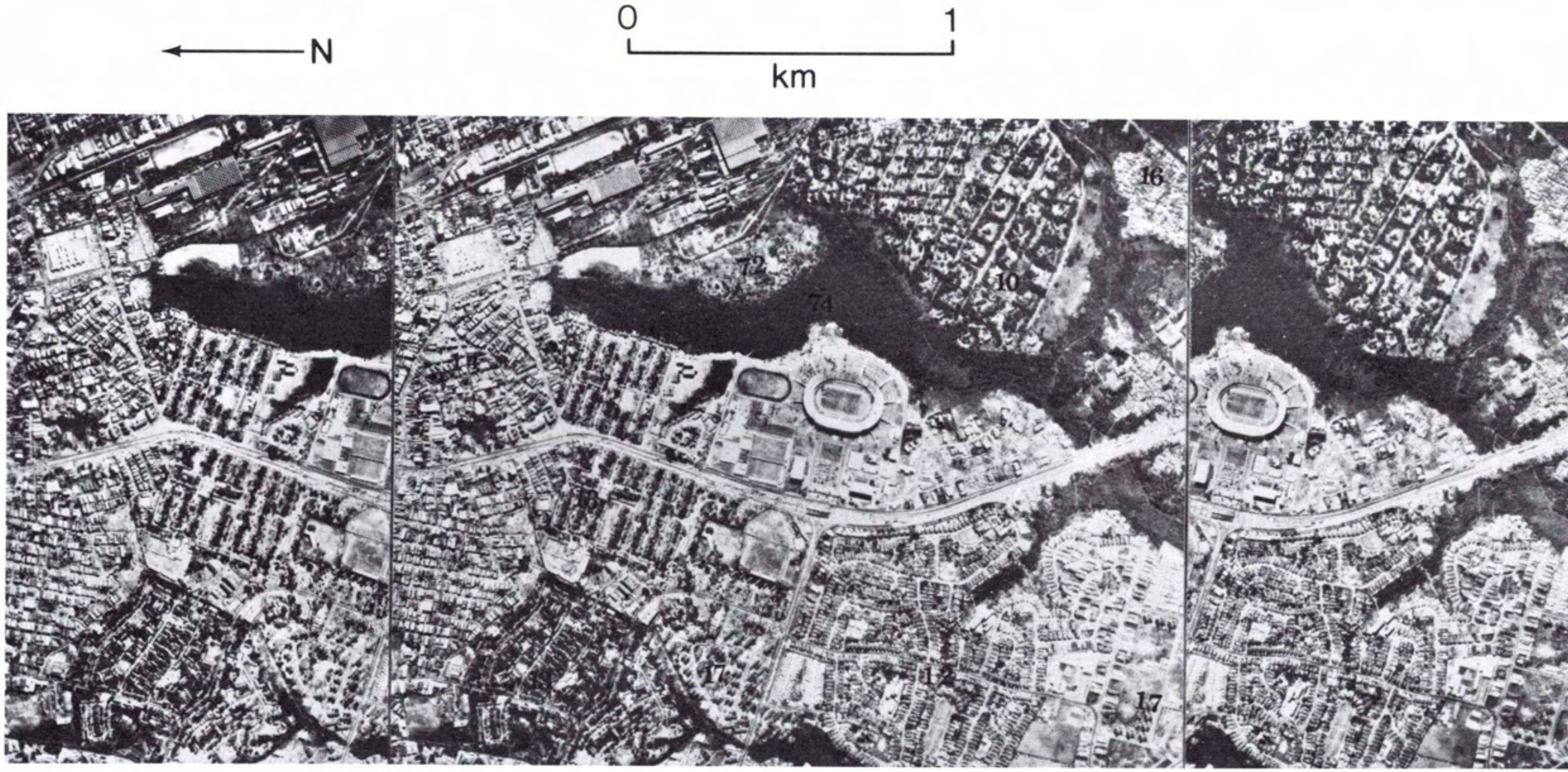

FIG. A-1. Stereotriplet of a part of central mainland Lagos 1974 (reproduced here at approx. 1:22,500 scale). This figure illustrates most of the residential types found in Lagos. The residential types shown on the figure are:

CLASS CODE	DESCRIPTION
10.	Large plot, 1-2 story flat buildings with vegetated open spaces. Mostly Government Residential Areas (GRA). Sub-division not allowed.
12.	Medium plot, 1-2 story 'flat' buildings with small individual open spaces. Residential class 11 is similar to this class except that the former contains mostly two story 'flat' buildings. Unlike class 12, which is essentially planned and developed by government agencies, class 11 is generally developed sporadically by private individuals.
13.	Single story row houses with common open spaces. Planned and developed by the government essentially for low income workers.
14.	Mixed traditional and modern 1-3 story buildings.
16.	Traditional single story rooming buildings
17.	Apartments (four story and above). Generally planned and developed by the government for different grades of workers.

Also shown are undeveloped (dry) vacant land (72) and undeveloped (wet) forested vacant land (74).

1. LAGOS ISLAND 1962 (1:40,000)

2. A STEREOGRAM OF A PART OF LAGOS ISLAND, 1974, (1:20,000)

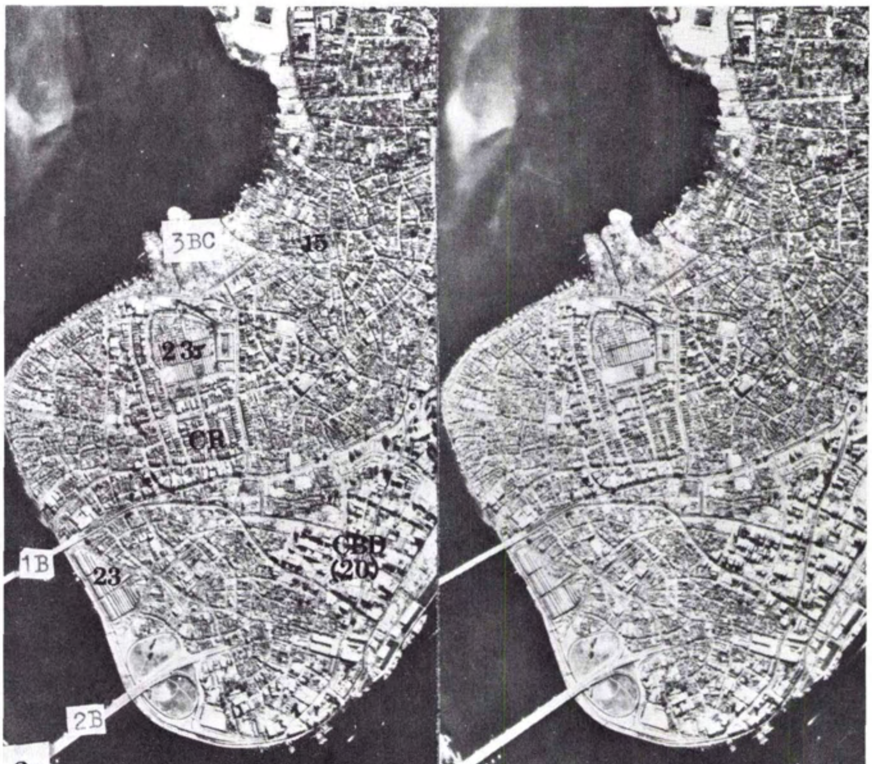

FIG. A-2. Lagos Island (1962 and 1974). Figure A-2(1) shows Lagos Island in 1962. Figure A-2(2) is a stereogram of a part of Lagos Island in 1974. The figure shows the old traditional "court-type" rooming buildings (residential class 15), the traditional market areas (code 23), and the central Business District (main commercial center, code 20). Also shown on the figure are the first bridge linking Lagos Island to the mainland in 1931 (1B), the second bridge in 1970 (2B), and the route for the third bridge which is now under construction (3BC). Note the land-use change where the second bridge enters Lagos Island. Considerable amount of commercial activities are carried out within the residential areas of Lagos Island. A particular area with intensive commercial activities is marked CR around the traditional market area of Jankara (23J).

Vacant lands. All parcels within the urban area not used for urban activity. Site under construction: Parcels of land on which are foundations of buildings and uncompleted buildings. Such lands are transitional and could not easily be classified into any particular urban use. This class is not difficult to identify on the photographs because of its tonal and spatial characteristics. Undeveloped (dry) vacant lands are usually found within the built-up areas and the immediate surrounding areas. Some are reclaimed land and some have roads on them. Undeveloped (dry) vegetated land is usually found in the fringe areas. The class is often difficult to separate from farm lands. The undeveloped (wet), non-forested vacant land includes the coastal and lagoonal marshy areas engulfed by urban development. It is discrete and found in many parts of Lagos. Some of these areas are used as public open spaces for refuse dumps. Undeveloped (wet), forested, vacant land consists of the deep inter-barrier and lagoonal swamps and marshes brought within the urban area by the development of the sand ridges. The classes of vacant lands are relatively easy to identify and delineate because of the tonal variations. The dry vacant lands have light tone (mainly sandy) and the wet lands in various dark tones. The minor variation in elevation shows up clearly in the stereomodel and this facilitates the delineation.

Non-urban land. All land not in urban or vacant land. The undifferentiated rural villages include 'agro' and fishing villages. Some of them are not easy to identify because of their poor contrast with their immediate surroundings. The agricultural plantation consists of modern farming areas with large plots. It includes large tracts of coconut plantation along the coast. The large size of the farms and the regular cropping pattern aid the identification. The farmland class consists of the traditional, scattered small farms (food production mainly) interspersed with pockets of fallow lands and overgrown bushes. Strictly, individual farms could not be mapped on the scale of photographs used. The forested wet lands consist mainly of palm trees, Avecinia mangrove, and many creeping plants. They occupy the valley bottoms and along the lagoons. The non-forested sparcely vegetated wet land is mainly found in the seasonally flooded flat sandy plains.

The area is covered with short aquatic grasses. For most of the year, the surface is covered with water. The shrub and secondary forest areas are usually former farmland areas which are gradually reverting to forest land. Within this class are scattered farmlands. It was difficult in certain areas to draw the boundary line between farmland and this class.

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(Received 21 September 1979; revised and accepted 11 April 1980)